NOTES FOR USE

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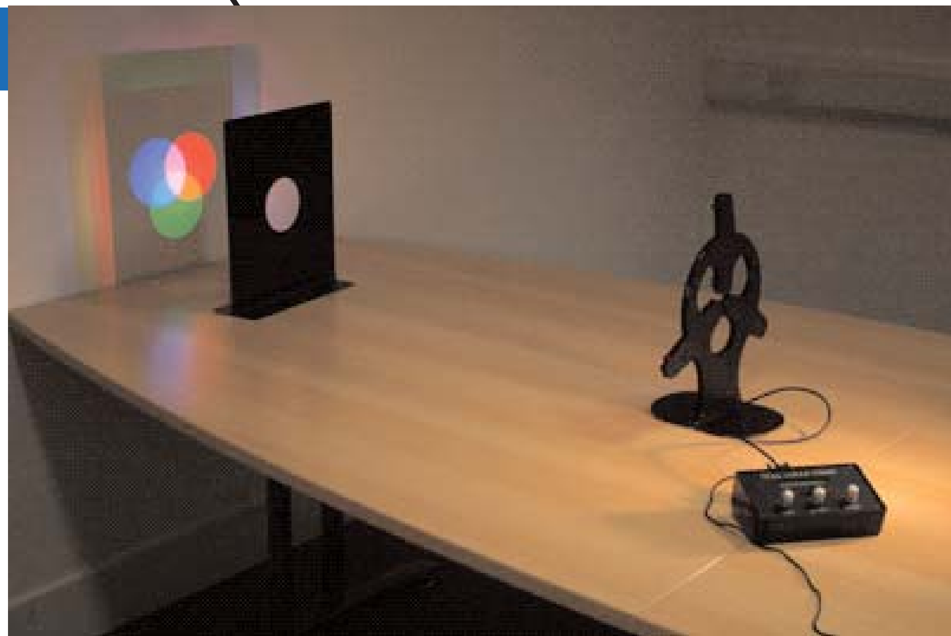
The Colour Mixer™

Notes for Use 720 UNILAB L75267
v. 06/03



FifeX and UNILAB would like to acknowledge the support of Jim Jamieson (SSERC) and the Fife schools, in developing this exciting new product.

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philip harris UNILAB®

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Description

The Colour Mixer™ is a robust and attractive device comprising 6 large, bright LEDs: two each of red, green and blue.

Their brightness is controlled by the dedicated Colour Mixer™ Control Box, powered by a plugtop power supply.

The outer or inner set of three LEDs can be selected, to allow a range of experiments, using the screens supplied.

Purpose

This kit is designed to help users explore the effects of colour mixing with light, and to support explanation of how colour is perceived.

Kit contents

Colour Mixer™
Colour Mixer™ Control Box
Plugtop 5V 1A d.c. power supply

plain, opaque white screen
black screen with circular aperture
clear screen with eclipse disc

Remove the protective plastic film from the three screens before using them.

Please note that each of the six LEDs should have an inset removable lens.
If any of these lenses is dislodged during transit, simply click it back into place.
If a lens is missing, contact your supplier for a replacement.

The Colour Mixer™

Inner LEDs selected

Outer LEDs selected

The Colour Mixer™ Control Box

The Colour Mixer™ Control Box has a three-position switch, to select the LEDs:

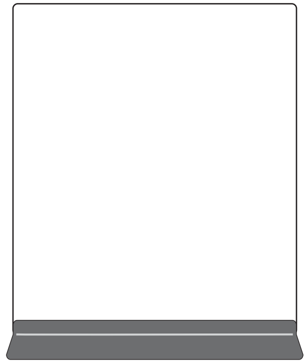
inner - off - outer

Three rotary controls set the brightness of the individual LEDs from 0 to 100%.

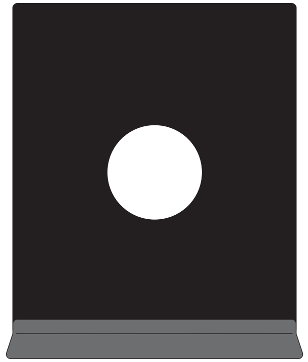
The brightness is continuously displayed.

The screens

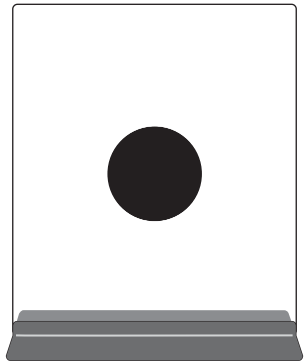
Plain white screen for displaying single or mixed colours



Black screen with aperture, for projecting circular patches of light



Clear screen, with eclipse disc for blocking light.



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Power supply

It is recommended that you use the 5V d.c. plugtop power supply provided.

Plug the power supply into a mains socket.

Connect the power supply lead to the jack socket on the back of the Colour Mixer™ Control Box.

Connect the lead from the Colour Mixer™ to the 9 pin socket on the back of the Control Box.

Switch on the mains socket.

Move the selector switch to left and right, to check that both sets of LEDs (inner and outer) are working.

In the experiments, the procedure above is given as "Connect and check the Colour mixer".

Safety

The Colour Mixer™ should be used under the supervision of a qualified teacher, with the plugtop power supply and Colour Mixer™ Control Box provided.

A risk assessment prior to use is recommended.

The LEDs in this product are "ultra bright", the Colour Mixer™ is a Class 2 LED product. Do not look directly at the LEDs from close range. Do not stare at any bright LED source.

Most experiments involve looking at objects illuminated by the LEDs rather than looking at the LEDs themselves.

When working in low ambient light levels, extra caution must be taken. Advise pupils not stare at the LEDs and to look for the minimum time necessary for experimental procedures.

We recommend that the audience be no closer than 1 metre to the Colour Mixer™.

The minimum table or bench area that we recommend for the Colour Mixer™ is 1200mm x 600mm. Around 1800 x 600mm is better.

FifeX and UNILAB accept no responsibility for injury or damage caused by misuse of the Colour Mixer™.

Useful extras

A4 or A3 tracing film, to act as a diffuser

large (A1) sheets of black and white matt card to use as backgrounds

Blu Tack

a plain white, common object, e.g. a plastic cup

stand, boss and clamp

a banana, lemon or grapefruit

a Kit Kat, a Coke can - and other products with graphics in predominantly primary colours (red, green, blue) plus white, e.g. Polo mints.

alphabet letters either:

printed on paper and cut out in a variety of primary colours; test these in advance as many inkjet printers will not produce good primary red, green and blue,

or

plastic, magnetic letters, with a suitable black magnetic board on which to arrange them to make messages; again, check in advance that the colours are good primary red, green and blue.

Explanations & Experiments

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1. Introduction to colour mixing

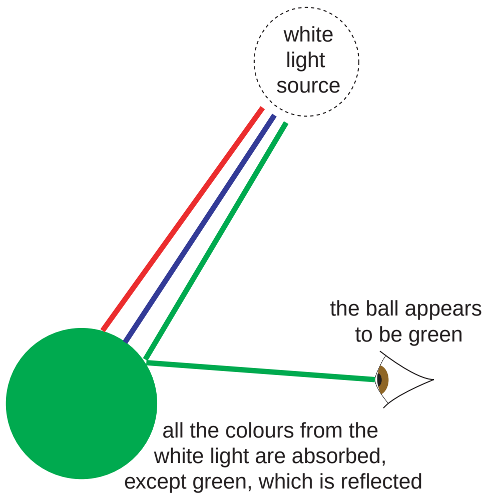
by Fergus Walker

The way we see light allows us to mix two or more colours to create new ones. However, coloured light does not mix to produce the same colours that you get when mixing coloured inks and dyes. This is because there are two kinds of colour mixing: additive and subtractive.

Colour vision

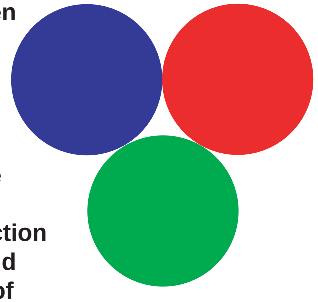
Before we learn about the two kinds of colour mixing let's check why things appear in colour. Remember that white light is a mixture of all the colours in the spectrum.

In the drawings, sets of red, green and blue lines are used to represent white light, instead of showing all colours of the spectrum.



Primary colours of light

Red, blue and green are usually described as the three primary colours of light.

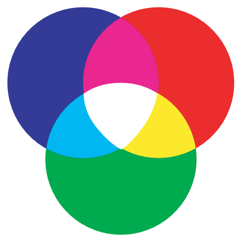


Later, you may like to read "Things to think about" in section 10 then discuss and research the idea of "primary"colours. For now we will accept the convention.

Additive colour mixing

If light of different colours is mixed, the intensities of the coloured lights are added together. This can be seen where the colour illumination overlaps.

The yellow mixed from red plus green will be brighter than either the red or green light alone.



red + blue = magenta
red + green = yellow
green + blue = cyan

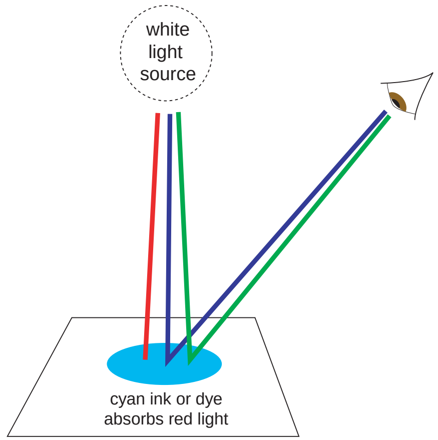
White light is an overlap of the three primary light colours.

By varying the intensity of the individual light sources, many, but not all colours can be obtained. TV screens and PC monitors use the additive colour process.

Primary colours of dyes and inks

The primary colours of dyes and inks are cyan, yellow and magenta. They are sometimes called the subtractive primary colours, because they subtract colours from the light passing through them.

Think of the ink on a sheet of white paper. The paper reflects all colours, but cyan ink absorbs, or subtracts, the red light.



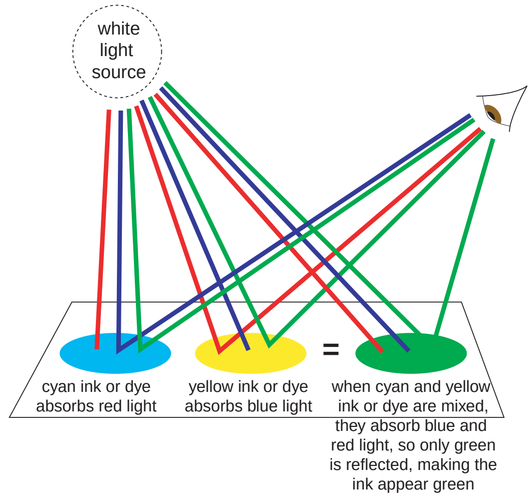
Subtractive colour mixing

When the subtractive primary colours are combined they produce the three additive primary colours: red, green and blue.

cyan + yellow = green
magenta + yellow = red
cyan + magenta = blue

The connection between the primary subtractive ink colours and the primary additive light colours, has led to the development of natural colours in fabrics, movies and printing.

Here the cyan dye or ink subtracts out red and reflects blue and green light, which makes cyan by additive mixing.
The yellow dye subtracts out blue and reflects green and red light, which mix to make yellow.



When you combine cyan and yellow dyes, the mixture subtracts out both red and blue. Only green reflected light reaches the eye. The mixture looks like green dye.

Now you can see why this is called subtractive colour mixing even though inks or dyes are added to each other. The coloured media absorb or subtract certain colours. When combined, the subtraction effect for both starting colours then works for the newly mixed colour.

For theories of colour vision, please refer to the text and links in section 8.

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2. Surface coloration

You will need:

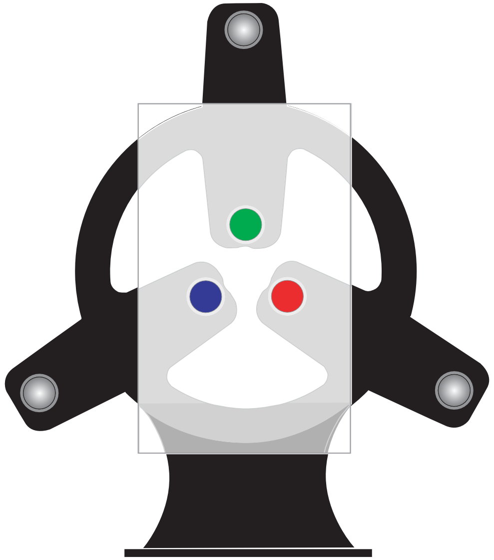
- the Colour mixer
- the Control box and power supply
- the plain white screen
- a darkened, but not blacked out room
- drawing film or tracing paper and some Blu Tack

Connect and check the Colour mixer.

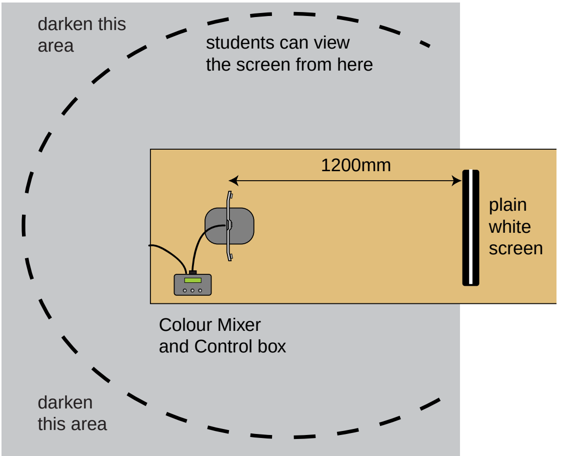
Turn all three controls down to 0%.
Set the switch to “inner”.

Place the plain white screen about 1200mm from the Colour mixer.

Attach a piece of tracing paper to diffuse the light from the inner LEDs only.



Students should sit so that they have a clear view of the plain white screen.



Ask students what colour the screen is. They will probably suggest white or grey, depending on the ambient light level.

Ask why, but do not worry at this point if they do not explain its appearance in terms of reflecting all colours.

Turn the red LED up to 100%. Turn it down to 0%. Do the same for the blue and green LEDs in turn.

Ask them to explain what they saw.
Lead them towards statements such as: “the colour of the screen depends on the colour of light it is reflecting”.

To avoid any suggestion that the screen is special, repeat the above, using a common, plain white object, e.g. a plastic cup, or even a toilet roll!

3. Colour mixing

You will need the same as in Section 2.

Set all the controls to 0% and ask students to watch the screen.

Turn the red LED up to 100%.
Turn the green LED up to 100%.

Invite comment from the students.
Remind them that the light that is falling on the screen is red and green.
They can ignore the ambient light because it should be at much lower level.

Turn the red LED down to 0%.
Turn the blue LED up to 100%.

Again, invite comment. The light reaching the screen is blue and green. Tell them that the colour they are seeing is usually called cyan.

Turn the green LED down to 0%.
Ask them what they expect to see when you add red light to the blue. It is likely they will suggest purple.

Turn the red LED up to 100%.
Tell them that the colour they are seeing is usually called magenta. Remind them that no magenta light is falling on the screen, only blue and red.

By convention red, green and blue are the primary colours of light. All other colours are the result of their eyes receiving mixtures of these primary colours.

Yellow, cyan and magenta are called the additive secondary colours of light.

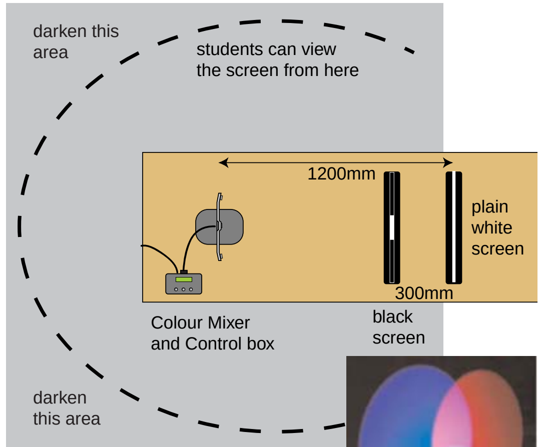
Ask what they expect if all three colours fall on the screen or other white object.

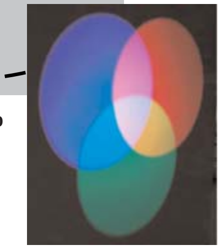
Turn all three LEDs up to 100%.
Invite their comments and adjust the proportion of each colour until most agree the screen appears white.

Discuss why they do not all agree. Each individual’s perception is slightly different, even if none of them is colour blind. They see the screen from different angle, and it is not a perfect reflector of all colours.

Turn the LEDs down to 0%. Move the switch from inner to outer. These LEDS are not diffused, and give a brighter image.

Place the black screen with aperture about 300mm from the white screen.





Turn the LEDs up to 100% one at a time.
Discuss and summarise what they have seen.

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4. Making a banana change colour

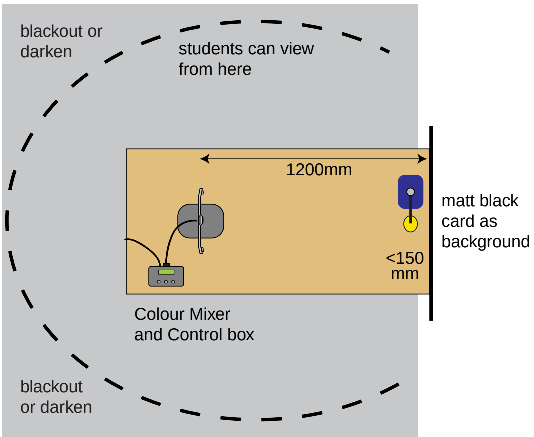
You will need:

- the Colour mixer
- the Control box and power supply
- a darkened room, blackout makes the effects clearer and more dramatic
- matt black card as a background
- stand, boss and clamp
- a banana, lemon or grapefruit

Arrange the matt black card about 1200mm from the Colour mixer. Fixing it to a wall with Blu Tack is recommended.

Connect and check the Colour mixer.
No tracing paper diffuser is required.

Set the Control box switch to “off”.
Turn all three controls up to 100%.



Normally, a banana (lemon or grapefruit) appears yellow, because it reflects the yellow part of the spectrum to your eye. We know already, that yellow light can be produced by mixing red and green light.

Support the fruit using a stand, boss and clamp, at a suitable height to be lit by the Colour mixer. Position it close to the black background - less than 150mm - this helps to reduce distracting shadows, which will be dealt with later (Section 6).

Switch on the inner LEDs.
When it receives white light (R+G+B) the fruit looks yellow. Students should be invited to explain this.

Turn the blue LED slowly down to 0%.
The fruit’s colour should change very little.
Invite explanation.

Turn the green LED slowly down to 0%.
The fruit should appear to be red.
If there is only red light to reflect, then it could not appear to be any other colour.

Turn the green LED back up to 100%, then slowly turn the red LED down to 0%.
The fruit should appear to be green.
Invite explanation.

Ask students how the fruit will appear if only blue light is used. Test their prediction and invite explanation.

Note, a banana will not appear to be black, as some of the blue light is reflected. Typically, it looks greyish and metallic.

5. Seeing things in black and white

You will need the same as in Section 4.

But instead of yellow fruit, you will need:
a KitKat, or a Coke can.

Connect and check the Colour mixer.
No tracing paper diffuser is required.

Set the Control box switch to “off”.
Turn all three controls up to 100%.

Support the KitKat or Coke can, close to the black background, at a suitable height to be lit by the Colour mixer.

Switch on the inner LEDs.
In white light (R+G+B) the graphics look quite normal. Two dramatic effects occur as the lighting is changed.

Turn the blue LED down to 0% and back to 100%. Turn the green LED down to 0% and back to 100%. In both cases, the change in appearance is slight.

Now turn the red LED down to 0%.

Invite explanation.
Lead them to a statement such as “when surfaces receive light that they are unable to reflect, they will appear black”.

Set all three LEDs at 100%, then slowly reduce the blue and green to 0%.
Invite explanation.

In ideal conditions, the red and white parts of the graphics both appear to be red. Both have only red light to reflect!

By careful choice of product, this can also be shown with blue and green light. Green and blue Gratnell storage trays give good results in this experiment, as their colours are close to the primary blue and green of the LEDs.

Students will have noticed the shadows in various colours, during the other demonstrations. Now that they have seen the behaviour of coloured light and its interaction with coloured objects, they are in a better position to investigate, in the next section.

6. Shadows in colour?

You will need:

the Colour mixer
the Control box and power supply

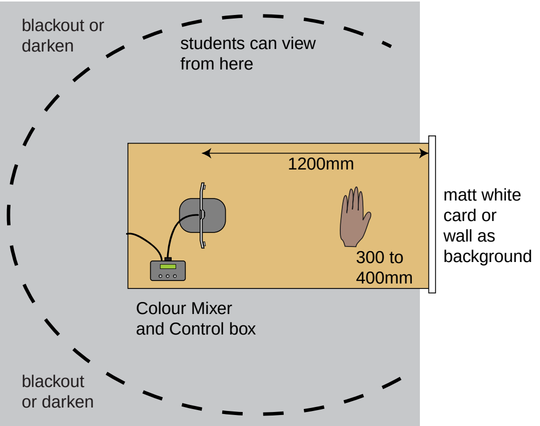
a darkened room, blackout makes the effects clearer and more dramatic

matt white card as a background

Arrange the matt white card about 1200mm from the Colour mixer. Fixing it to a wall with Blu Tack is recommended. Connect and check the Colour mixer. No tracing paper diffuser is required.

Set the Control box switch to "off". Turn all three controls up to 100%.

Switch on the inner LEDs.



Ask a student to place a hand between the Colour mixer and the white background or wall, about 300 to 400mm from the background.

Discuss the images on the screen.

Switch to the outer LEDs for a more dramatic effect.

Suggest the student moves their hand closer to the white background, then closer to the Colour mixer.

Ask whether the student can produce a single shadow, in yellow, magenta or cyan. They should soon realise that moving closer to one LED will block it and give the desired colour of shadow, as follows:

blocking blue gives a yellow shadow
blocking green gives a magenta shadow
blocking red gives a cyan shadow

Shadows are produced by preventing some light from reaching the screen. The yellow shadow is lit by red and green, but not by blue.

Ask the student to hold their hand steady, about halfway between the Colour mixer and white background. A number of coloured shadows should be visible on the background.
Challenge others to say which LED to turn off to get rid of the cyan shadow.
Do the same for the magenta shadow.

The pairs of colours:

blue - yellow
green - magenta
red - cyan

are called "complementary". Putting any pair together gives white light.

To deal with these coloured shadows more formally, place the clear, eclipse screen about 300mm from the white background.

The outer LEDs should all be at 100%.

The black central area is receiving NO light, so it appears black. It is a shadow.

The three circles are also shadows, as that is the only way a circular shape could be produced on the white background.

The area outside the three overlapping circular shadows is receiving all three colours, so it appears approximately white.

Invite explanation of the coloured shadows observed on the white background.

Students should be guided to reason as follows:
'If it looks yellow, then it is reflecting red and green light to my eye. Blue light is not reaching that part of the background'.

It is interesting to note that this whole image can be related to the "rules" for subtractive mixing of inks and dyes.
See Section 1 and "Questions and things to think about".

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7. Secret writing using coloured letters

You will need:

- the Colour mixer
- the Control box and power supply
- a darkened room, blackout makes the effects clearer and more dramatic
- matt black card as a background
- a supply of cut out letters printed in primary (and other) colours and some Blu Tack OR
- a black magnetic board and magnetic letters in primary colours

Arrange the matt black card about 1200mm from the Colour mixer. Fixing it to a wall with Blu Tack is recommended.

Connect and check the Colour mixer. No tracing paper diffuser is required.

Set the Control box switch to “off”. Turn all three controls up to 100%.

First of all, make single words, out of coloured letters, each word in a single colour, red, green, blue and yellow.

Switch the inner LEDs on.

All four words should be clearly visible.

Try the effect of turning each LED down to 0% in turn.

If the coloured letters are close to primary red, green and blue, then they should become nearly black and therefore almost invisible against the black background.

Invite explanation of the behaviour of the word in yellow.

Using a large number of coloured letters, it is possible to conceal a message (in one colour) within a random slection of letters in other colours. The message becomes visible only when the correct colour of light falls on the letters.

In the example below, two messages are concealed; one in green, the other in red.

8. Theories of colour vision

Young-Helmholtz “trichromatic” theory - (mid 19th century) proposed that the human eye contains three systems of colour perception, with maximum responses to three primary colours. This theory was adopted and enabled colour photography to be developed.

There is little biochecmical support for the theory, but the practice is justified by the physical possibility of matching practically every natural colour by the addition of contributions from the three primary colours.
Larousse Dictionary of Science and Technology

Hering’s Opponent Process Theory - (early 20th century) Hering observed that the "trichromatic theory" could not explain the phenomenon of afterimages, negative-coloured images seen after extended viewing of a coloured object (e.g. red after green, or yellow after blue).

Hering based his work on the subjective appearance of colours, and wondered why certain colours could never be seen or even described, such as bluish-yellow or reddish-green.

Hering proposed that the visual system generated signals in opposing pairs (i.e., yellow-blue, red-green, white-black). However, it was not until much later in the twentieth century that neural experiments proved him correct. At the time his theory was seen by many to compete with the trichromatic theory.

Hering himself held that both theories could be equally valid. We now know that he was correct - the two theories simply reflect processes at different levels of visual processing.
University of Calgary, Dept. of Psychology
www.psych.ucalgary.ca/pace/va-lab/Brian/history.htm

Frequently asked questions about Colour physics - sponsored by Konica Minolta
www.colourware.co.uk/cpfaq.htm

9. Interactive Powerpoint sequence

On the CD you wil find a Powerpoint sequence called “Colour mixing”. This has been included with the kind permission of its author, Don Evans of King Edward VI Aston School.

Colour mixing

This and other resources were first published on the Teacher Resource Exchange, www.tre.ngfl.gov.uk in the Science section.

The sequence allows teachers and students to explore the “rules” of colour addition and subtraction, and check what they have learned using the Colour Mixer. It can be used to good effect on an interactive whiteboard.

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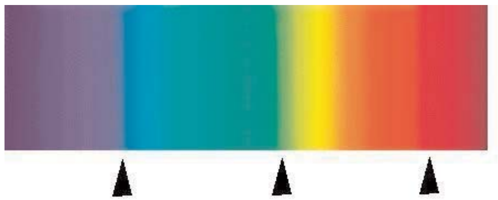
Questions and Things to think about

1. What are the primary colours of light and what are the secondary colours?

Primary: red, green and blue
Secondary: cyan, magenta and yellow

BUT red, blue and green are not actually special - they are just three particular wavelengths of light, chosen from the visible spectrum.



They are called the primary colours for additive mixing, but other sets of three colours could have been chosen.

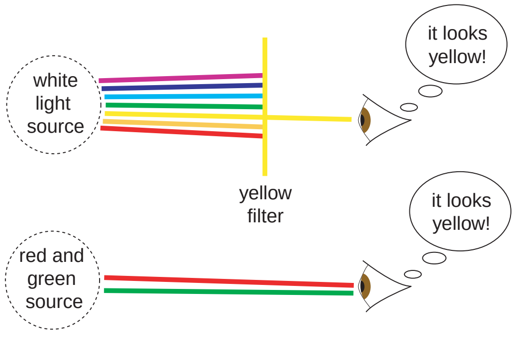
The important feature is that they combine by additive mixing, to give a wide range of colours.

It is now convention to call these three colours “primary” and their use in the production of images on computer screens and TVs is widespread.

They are able to produce the effect of a wide range of colours, but it is not true to say that all colours can be made by mixing red, green and blue light. Try brown!

2. Is it really yellow?

The human eye cannot tell the difference between pure yellow light, selected from white light by filtering, and yellow light produced by mixing red and green.



Some optical instruments can detect the difference, and show that the light received is a single wavelength, or a mixture of two wavelengths.
Our eyes cannot distinguish.

3. What are the primary colours of paint, pigments and dyes?

Primary: cyan, magenta and yellow

Again, it is convention that these three colours are called primary. Another set of three colours could have been chosen.

The important feature is that they combine by subtractive mixing, to give a wide range of colours.
All three should mix to give black, but actually give a brownish result.
Colour printers use four colours:
cyan, magenta, yellow and black.

4. How are the primary colours of paints and dyes related to additive and subtractive colour mixing and what is the difference?

Additive colour mixing is the term used to describe colour mixing with light

Subtractive colour mixing is used to describe colour mixing with dyes and pigments.

These types of colour mixing are different: green and blue light will not give the same result as mixing green and blue paint.

In additive colour mixing, the addition of a new colour adds to the mix, increases brightness and brings the combined colour closer to white.

In subtractive colour mixing, the addition of a new colour removes reflected colour from the mix, making the mix less bright and bringing the overall colour closer to black.

See the absorption section below for more on this.

5. Why (in section 1) did we represent all the colours of the visible spectrum (white) using only red, green and blue?

The spectrum can be roughly split into these three main colour bands, and to keep the illustration simple!

6. What happens in our eyes when we mix two colours of light , why do we see the secondary colour?

In the cone theory, it is assumed that our eyes have three types of cone or detector. When any <u>two</u> types of cone are stimulated our brain receives the sensation and we have learned how to interpret the sensation.

When our eye detects blue and green light, we have learned to call the sensation, “cyan” or maybe “turquoise”.

Again see the absorption section for more on this.

7. What happens if you are colour blind, and why do some people perceive colours differently?

Some people have a deficiency in their cones meaning that the way they perceive colours is inaccurate.
A few people have one type of cone that is completely deficient, so they cannot recognise that colour.

8. Why are the pairs of colours:

blue - yellow
green - magenta
red - cyan

called “complementary”?

Because they make white light when mixed in the right proportion. Yellow is red + green, so adding blue gives all three primary colours which make white.

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9. If an object is yellow, why do we see it as yellow and what happens if we only shine blue light onto a yellow object?

It is reflecting yellow light to our eyes, OR it is reflecting red and green light and absorbing blue.

Refer back to question 2, and also section 3, Colour mixing.

So, if you only shine blue light on a yellow object it should be perceived as black because it cannot reflect the light that we are shining at it.

10. Can you trick your brain to think of something is a different colour from what it actually is and what objects work best?

It can be very convincing but there must be no light at all in the room, otherwise it will not work.

Take great care if you decide to try this in total darkness.

Try using bananas, daffodils, lemons, limes, strawberries so that there will be a marked change if they “turn black”.

Multi-coloured objects also work well as changing the colours will completely alter how they look. Aim for an object with colours that are close to the primary or secondary colours (R, G, B, C, M, and Y).

11. How do you explain subtractive colour mixing?

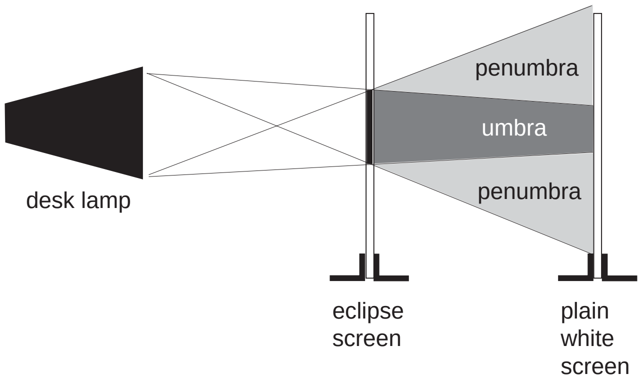
This is very simplified and doesn't take into account the amounts of each pigment or indeed the shade

Something that is yellow is reflecting red and green and absorbing or “subtracting” blue. Something that is magenta is reflecting blue and red and absorbing green. Therefore mixing yellow and magenta will give you red because both green and blue are being absorbed. ().

12. How does an eclipse happen?

Use the eclipse screen with a normal desk lamp, with a large (150 to 200mm) circular reflector. Direct the lamp horizontally, to cast a shadow of the eclipse disc on to the white screen.

Adjust the distance between the eclipse disk and the screen, to explore the phenomenon of umbra (full shadow) and penumbra (partial shadow).



Attach large (200mm) and small (50mm) disks of white card to sticks, so they can be moved in and out of the shadow.

You should be able to simulate both lunar and solar eclipses.

Lunar eclipse

The smaller disk represents the Moon, and should be moved through the shadow, fairly close to the eclipse screen, which represents the Earth.

In a lunar eclipse, the Moon is small relative to the Earth’s shadow (umbra), and takes a long time to pass through it.

Solar eclipse

Take away the plain white screen.

The eclipse screen now represents the Moon. The larger card disk represents the Earth, and should be moved across the tip of the umbra, which is some way beyond the eclipse screen.

In a solar eclipse, the Earth is large, relative to the Moon’s shadow (umbra).

The umbra is only just long enough to reach the Earth, and the shadow moves quite rapidly across the Earth’s surface.

The area of shadow is quite small, which is why each solar eclipse is only total along a narrow strip of the Earth’s surface.

Online support

Further information including examples of experiments for colour mixing can be found at www.fifex.co.uk/fcmonline.htm

You are invited to submit ideas for new experiments or suggestions for improving the experiments presented here, to the same website.

We recommend the following website for information on colour mixing www.rgbworld.com/color.html

Troubleshooting

If the LEDs do not light, check that:

- the plugtop power supply is connected to a mains socket that is switched on
- the miniature power jack is plugged into the socket on the back of the Control Box
- the lead from the Colour Mixer is plugged into the socket on the Control Box
- the controls are all turned up to 100%, i.e. fully clockwise
- the selector switch is set to either “outer” or “inner”

If the Colour Mixer or Control Box does not operate correctly, contact your supplier for advice.